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Crop residue biomass for decentralized electrical power generation in rural areas (part 1): Investigation of spatial availability

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ABSTRACT

Spatial assessments of crop residue biomass and its power potential at village level in Sonitpur district of Assam, India is presented in this paper. Recent IRS P6 LISS-III remote sensing data of the study area is analyzed in GIS environment to map crop areas and subsequently residue biomass availability at village level. Altogether 16 different types of crop residues are identified in the district with rice crop as dominant residue. About 0.17 million tonnes of crop residue biomass, having about 17 MW potential power, is spatially distributed in the rural areas of the district. Village level biomass power mapping is done assuming combustion route of decentralized power generation. Considering the acute shortage of grid connected power supply in the study area, the decentralized crop residue based power generation could be an attractive option. At individual level, thermal power plant up to 72 kW could be possible to cater the essential power need of the villager.

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1. Introduction

The demand of electricity is increasing day by day worldwide and is likely to increases by many folds in the fast growing economies like India, China and Brazil. Till date, the major quantum of the demand is met through fossil fuels, but the associated GHGs emission from burning of fossil fuel has been the top global environmental concern. Diminishing fuel reserves, precarious oil markets are some other issues apart from global warming which forced almost all the nations to search for renewable energy for future energy security. It is projected that globally per capita energy demand (tonne of oil equivalent) would increase from 1.8 in 2007 to 2.0 in 2030 and subsequently per capita CO_2 emissions (tonne) would increase from 4.4 in 2007 to 4.9 in 2030 [1]. Considering the exponential growth of population in major parts of the globe,

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such increase would result excessive pressure on fossil resources which have inherent problems as mentioned above. Thus, significant share of future energy has to come from renewable energy sources to meet the projected demand and to halt GHGs emission at an acceptable level. However, growth of renewable energy is not encouraging and is yet to be realized in many countries. Till date, only 18% of global electricity is met by renewable sources and without hydropower it is only 2.5%. [2]. In India, as on July 2010, out of the total installed power capacity of 163.7 GW, more than 53% alone is contributed by coal and the share of renewable energy sources is only about 10% excluding large hydropower projects. [3].

Biomass, wind, solar, hydro, geothermal and marine are the technically feasible components of renewable energy system used with different degree of intensities all over the world up till now. Heat, electricity, fuel (solid, liquid and gaseous) and mechanical energy are the outputs of renewable energy system. It is reported that biomass energy alone can provide the half of the present global primary energy consumption by the year 2050 and in many developing countries it is the source of 35% of primary energy consumption (including traditional uses of biomass) [4]. Biomass is a distributed resource and estimated as one of the major renewable resource in India also. Renewable energy resource availability varies amongst the regions in India. Therefore, the region specific planning is required for the required uniform growth of renewable energy amongst the regions. The strength of locally available renewable energy resources could be utilized for the economic development.

Assam situated in the North-Eastern part of India, despite of its large potential in natural resources, lags behind the rest of the country in terms of economic and social development. Per capita income of the state is 28% lower than the national average and is half of the state of Punjab, one of the prosperous states of India [5]. About 85% of population of Assam is living in rural areas and primarily dependant on agriculture. The agricultural productivity of the state is also much lower than the national average. The productivity of rice in Assam is 30% lower than the national average, and is about 62% lower than Punjab [6]. Deficient supplies of critical inputs, including power, are considered as one of the reasons of lower farm productivity.

Contrary to favourable potential for growth of renewable energy in Assam, the progress is very sluggish. For example, contribution of Assam to the nation's 15.62 GW grid connected renewable power (consisting 70% wind, 16.5% small hydro, 13% biomass and 0.5% others) is only about 0.17% [7]. The identified small hydropower potential in the state is about 239 MW, but the installed capacity is only 27 MW. However, the assessment made by the latest geospatial technique and hydrological modeling covering a small watershed indicate higher level of availability than the traditional estimation [8]. It is also reported that the state of Assam has agro based biomass resources with an equivalent power potential of about 279 MW of which about 203 MW is contributed by rice crop residues alone [9]. Thus, biomass and small hydropower could be promising options for renewable energy development in Assam. However, the comprehensive assessment mentioned above could only be guidelines. Precise assessment targeting smaller spatial units would be required for planning and implementation of effective renewable energy programmes.

Biomass resources include wood and wood wastes, agricultural crops and their waste by-products, municipal solid waste, animal waste, waste from food processing and aquatic plants including algae [4]. Conversion of biomass for power generation is a matured technology and successfully demonstrated in many parts of the world including in India [10–16]. Several megawatt level biomass based projects have been successfully operating in India. For example, a 25 MW biomass power plant with agro-waste and wood as inputs in equal proportion has been commissioned in Karnataka in 2004. Similarly, two 6 MW power projects, one with a mixture of biomass (90%) and coal (10%) and another with rice husk (45%), woody biomass (40%) and coal (15%) have been installed in Andhra Pradesh [17].

Table 1
Details of remote sensing data.

Satellite	IRS P6
Sensor	LISS III
Swath	141 km × 141 km
Spatial resolution	23.5 m
Cloud cover	Less than 3%
Acquisition dates (path, row)	19 November, 2008 (111, 52) 19 November, 2008 (111, 53) 24 November, 2008 (112, 53)

Crop residue biomass (*CRB*) is distributed over large geographical areas and requires precise estimation at both spatial and temporal level for successful bioenergy programme. Moreover, collection and transportation system should also be part of planning for sustainable utilization. Many authors have reported the use Geographical Information System (GIS) in biomass resource assessment and planning [18–23]. However, most of the studies are aimed at regional or country scale planning for megawatt size power plants, with lack of prominence for smaller geographical and administrative units.

Revenue Village is the smallest units of administration in India. Government of India has stressed village level planning and implementation of the most of its developmental programme. There have been many success stories of decentralized planning and implementation of developmental programme in India [24,25]. Examples are also available for rural decentralized power programme [10] in several places in India.

As mentioned earlier, success of such rural decentralized power programme would necessitate precise mapping of village resources. As the strength of rural areas mostly lies on the crop residue biomass, therefore, village level CRB mapping for decentralize crop residue biomass power (*CRBP*) will be critically important. Success of such decentralized power generation programme would result multifaceted benefits to the rural people. First, the conversion of non-commercial residue into valuable by-product would fest some additional income to the farmers. Second, the engagement of the rural people in collection and transportation chain would generate employment. Third, but the most significant contribution of decentralized power generation would be the development stimulated by assured supply of electricity. This is particularly important for the state of Assam, which has been chronically power deficient affecting all section of rural population.

Keeping in view the above discussion, village level *CRBP* plant seems to be one attractive option in Assam and thus, the present study is conducted targeting rural areas in Sonitpur district of Assam, India.

The objectives of the present investigation are to (i) assess spatial availability of crop residue biomass and (ii) assess village level crop residue biomass power potential.

2. Methods and methodology

2.1. Remote sensing and other ancillary data

IRS-P6 (Indian Remote Sensing Satellite) LISS III (Linear Imaging and Self Scanning Sensor) multi-spectral remote sensing data pertaining to the study area of November, 2008 is collected from National Remote Sensing Centre (NRSC, Government of India). Details of the data are given in Table 1. The study area falls across three scenes, hence the scenes are subsetted and mosaicked to

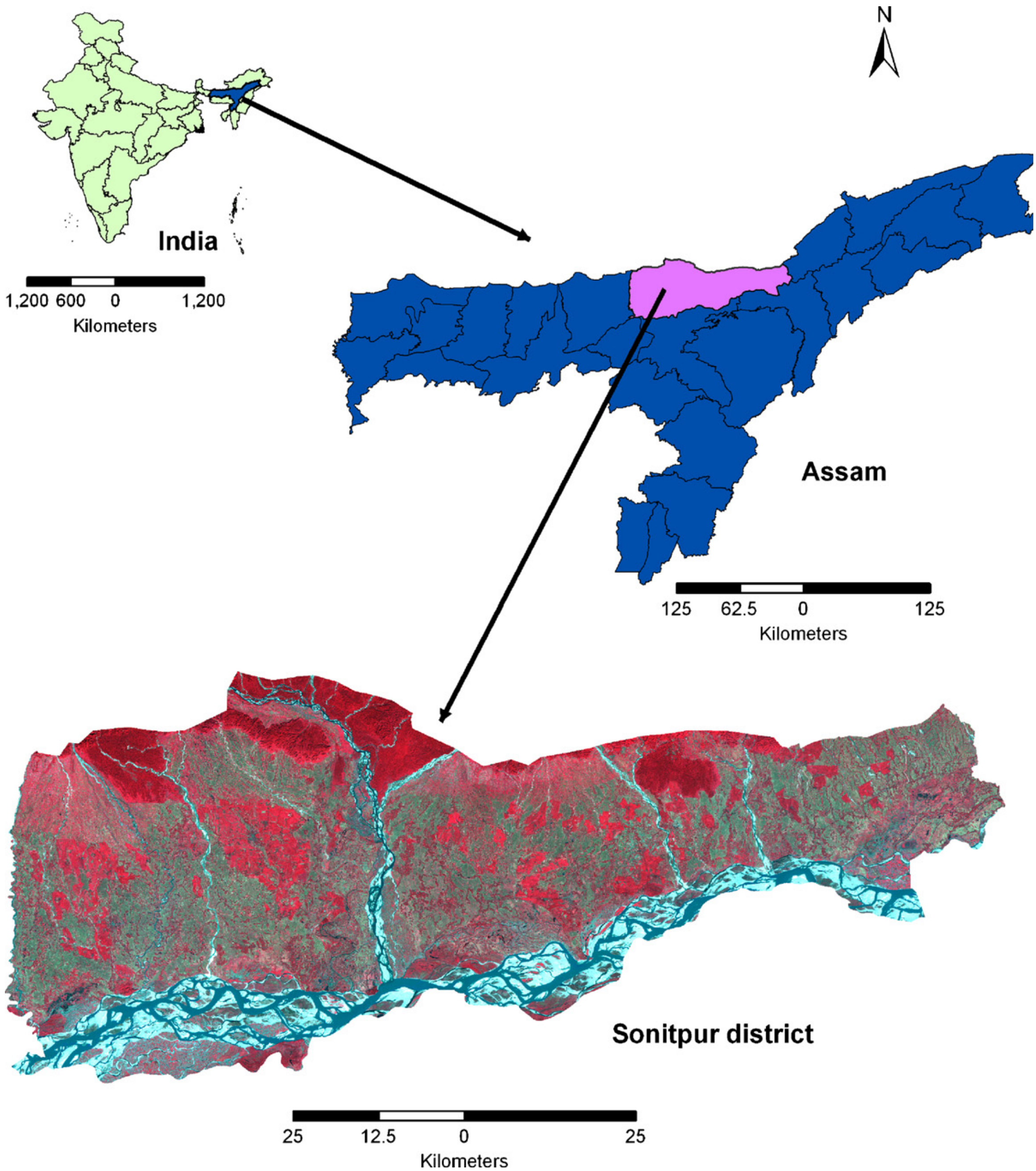


Fig. 1. Geographical location and IRS P6 LISS III FCC of Sonitpur district.

make a single raster layer covering the entire study area. Survey of India (SOI) 1:50,000 topographical maps are used as reference maps for georeferencing the satellite images. District administrative boundary maps and development block (DB) maps are provided by the administration of Sonitpur district. Village map of Sonitpur district provided by the North Eastern Regional Institute of Water and Land Management (NERIWALM), Sonitpur, Assam is used.

2.2. Study area

Sonitpur is one of the 28 districts of Assam lying in between 92°16′E, 93°43′E longitudes and 26°30′N, 27°0′N latitudes (Fig. 1). The total geographical area of the district is 5324.00 km^2. For convenience of local administration, the district is geographically divided into 14 DBs comprising 3051.00 km^2, excluding major rivers and reserve forests. The average summer and winter temperature of the region are reported as 29 °C and 16 °C respectively. On the other hand, the annual rainfall in the district varies between 1355 and 2348 mm.

2.3. Selection of agricultural crops

In the present study, *CRB* available from all the major crops cultivated in the district as given in Table 2 is considered.

2.4. Spatial mapping of crop residue biomass power

Spatial mapping for biomass power is done using the information of spatial distribution of crop residue biomasses from all the crops under consideration on annual basis. In general, rice based farming system prevails in Assam. Therefore, avail-

Table 2
Agricultural crops and their residue.

Crop	Type of residue biomass	
Rice	Husk	Straw
Wheat	–	Straw
Maize	Cobs	Stalk
Gram	–	Straw
Pigeon pea	–	Stalk
Lentil	–	Straw
Green gram	–	Straw
Black gram	–	Straw
Peas and beans	–	Straw
Sesame	–	Straw
Rapeseed and mustard	–	Straw
Linseed	–	Straw
Sugarcane	Leaves and tops	Bagasse

able satellite image concerning the growing period of winter rice (June–December), which is a major crop of this region, is considered to map the cropland. The details of the mapping procedure are given below.

2.4.1. Mapping of cropland for rice crop

Prior to interpreting and mapping the features present in a satellite image, accurate geometric rectification is an important aspect. The satellite imagery is geometrically rectified into a Universal Transverse Mercator (UTM) projection using ground control points (GCP) taken from SOI topographic maps of 1:50,000 scale. While georeferencing, GCPs are chosen in such a way that they can be easily identified both in the topographic map and satellite image (e.g. road and railway line crossings). The image registration is also verified with the GCPs collected during field verification. A false colour composite (FCC) of the bands 2 (green), 3 (red) and 4 (near IR) displayed to blue, green and red colour, respectively, is then created.

Mapping is carried out using GIS software ArcGIS 9.2. While interpreting and delineating the rice fields, guidelines for IRS-P6 LISS III image interpretation provided by the National Remote sensing Centre (NRSC), India are followed [26]. Accuracy assessment is determined in terms of Kappa accuracy as per the procedure described in [26]. After mapping the rice fields, village wise availability of rice crop area is estimated by overlaying the rice field vector layer with the village vector layer using Overlay analysis function of ArcGIS 9.2.

2.4.2. Mapping of cropland for crops other than rice

The district level production statistics of all other crops (except rice) are used to map their respective cropland. The village level spatial maps of these crops are generated with an assumption that crops other than rice are grown in proportion to rice area.

2.4.3. Estimation of crop residue biomass

After mapping the cropland, the spatial availability of *CRB* is estimated using the following expression

$$TCRB(j) = \sum_{i=1}^{n} R(i,j) \times Y(i,j) \times A(i,j) \tag{1}$$

where *TCRB*(*j*) is the theoretical crop residue biomass availability at *j*th location from all crops, tonne; *R*(*i*,*j*) is the residue production ratio of *i*th crop at *j*th location; *Y*(*i*,*j*) is the yield of *i*th crop at *j*th location, tonne ha^{-1} and *A*(*i*,*j*) is area of *i*th crop at *j*th location, ha.

Spatial variations of *R*(*i*,*j*) and *Y*(*i*,*j*), attributed mainly by crop variety, soil type, agricultural practice *etc.*, are not considered in the present study. The value of *R*(*i*,*j*) for the crops considered in the study have taken from available literature [9] and given in Table 3.

Table 3
Residue production ratio of different crop residues.

Crop residue	RPR
Rice straw	1.50
Rice husk	0.20
Wheat straw	1.50
Maize cobs, stalk	0.30, 2.00
Gram straw	1.10
Pigeon pea stalk	2.50
Lentil straw	1.80
Green gram straw	1.10
Black gram straw	1.10
Peas and beans straw	0.50
Sesame straw	1.47
Rapeseed and mustard straw	1.80
Linseed straw	1.47
Sugarcane leaves and tops, bagasse	0.05, 0.33

Further, 5-year average yield of crops grown in Sonitpur district during 2003–2007 as reported by Ministry of Agriculture, Govt. of India is used [6].

Eq. (1) is used to estimate the theoretically available *CRB*. However, the practical availability of *CRB* is limited by its competitive uses, harvesting and threshing practices, and methods of collection of leftover portion. Traditional uses of crop residue, particularly rice straw as feeds for livestock and as fuel are common for farmers in Assam. However, in some special cases, compost making to support soil fertility and soil organic matter and papermaking are also practiced [27]. More are the competitive uses, lesser is the availability. The harvesting and threshing practices have remarkable influences on practical availability of *CRB*. With manual methods of harvesting, there are wide variations of height of cut and accordingly its availability. To incorporate such uncertainties, practically available *CRB* is estimated using an availability factor as given below

$$PCRB(j) = \sum_{i=1}^{n} R(i,j) \times Y(i,j) \times A(i,j) \times F(i,j) \tag{2}$$

where *PCRB*(*J*) is the practically available crop residue biomass at *j*th location, tonne; and *F*(*i*,*j*) is the residue availability factor of *i*th crop at *j*th location. In the present study, the crop wise as well as spatial variations of *F*(*i*,*j*) is not considered. The value of *F*(*i*,*j*) for rice straw and other remaining crop residues is taken as 50% and 80%, respectively. Gadde et al. [28] reported a similar value of 48% surplus rice straw availability for the states of Punjab and Haryana of India, while Singh et al. [22] reported surplus rice straw availability in Punjab as 83.5%. For rice husk and other crop residues, a similar availability factor of 75% also reported by Purohit [29].

2.4.4. Estimation of crop residue biomass power potential

Conversion of biomass to energy is undertaken using two main process technologies viz., thermo-chemical and bio-chemical. Combustion, pyrolysis, gasification and liquefaction are distinguishable thermo-chemical conversion processes. Similarly, bio-chemical conversion encompasses digestion (biogas) and fermentation (ethanol) [30].

Amongst the thermochemical conversion technologies, combustion is a matured technology specifically suitable for loose biomass [31]. The combustion process converts chemical energy stored in biomass into heat, mechanical power and electricity using various equipments, e.g. furnaces, boilers, steam turbines and generators. It is possible to burn any type of biomass with a moisture content of less than 50% [30]. Literatures are available citing typical size of combustion based biomass power plant from a few kilowatts up to 100 MW with net conversion efficiency between 20% and 40% [4,30,31].

The lower heating value (LHV) is an important parameter that is used to estimate energy potential of *CRB*. Using the LHV, the energy potential is estimated as follows

$$CRBE(j) = \sum_{i=1}^{n} R(i,j) \times Y(i,j) \times A(i,j) \times F(i,j) \times C(i,j) \qquad (3)$$

where *CRBE*(*j*) is the crop residue biomass energy at *j*th location, MJ and *C*(*i*,*j*) is the lower heating value of the *i*th crop at *j*th location, MJ tonne^{-1}. The spatial variation of *C*(*i*,*j*) is not accounted in the present investigation. The LHV of crop residues reported in literature is used in the present analysis [22].

Incorporating net conversion efficiency for biomass combustion and duration of operation, power potential is determined as given in the following expression

$$CRBP(j) = \frac{K \times \sum_{i=1}^{n} R(i,j) \times Y(i,j) \times A(i,j) \times F(i,j) \times C(i,j)}{T} \qquad (4)$$

where *CRBP*(*J*) is the crop residue biomass power at *j*th location, MW; *K* is the overall energy conversion efficiency, and *T* is the annual operating duration, seconds. Continuous operation throughout the year is considered for assessment of power. A conservative value of *K* as 20% is considered for the present study.

3. Results and discussions

3.1. Spatial availability of crop residue biomass

Crop wise residue biomass availability of Sonitpur district is presented in Table 4. Theoretical availability of *CRB* in Sonitpur district is estimated as 0.28 million tonnes, out of which 0.17 million tonnes would be practically available for bio-energy. Rice, sugarcane, rapeseed and mustard are the crops contributing major portion of residues with their share as 70%, 15% and 9%, respectively.

Rice based mono-cropping has been the predominant practice till now in Assam. However, with the increase of farm power availability and emphasis by the Government to increase crop intensity with more number of crops per year, it is expected that the residue shares of other crops like oil seeds and pulses would also increase. Moreover, such increase in cropping intensity would also enhance the spatial and temporal availability of crop residue in near future.

Table 4
Crop residue biomass availability in Sonitpur district.

Residue type	Practical availability, tonne	% share
Rice straw	94,338.30	57.71
Rice husk	20,125.50	12.31
Wheat straw	4432.18	2.71
Maize straw	869.06	0.53
Maize cob	130.36	0.08
Gram straw	119.08	0.07
Arhar stalk	781.39	0.48
Lentil stalk	614.74	0.38
Green gram straw	340.46	0.21
Black gram straw	1197.47	0.73
Peas and beans straw	424.24	0.26
Sesame straw	645.48	0.39
Rapeseed and mustard	14,836.16	9.08
Linseed straw	201.71	0.12
Sugarcane leaves and tops	3210.86	1.96
Sugarcane bagasse	21,191.65	12.96
Total	163,458.62	100.00

The district of Sonitpur has 1502 villages under 14 development blocks. Development blocks are the smallest administrative units for planning, monitoring and implementing developmental programmes in rural areas. Village level spatial *CRB* mapping (tonnes of residue biomass) of Sonitpur district is developed using relevant inputs and standard procedure which is presented in Fig. 2. The cropped areas of the district are typically sandwiched between reserve forests in northern side and the river Brahmaputra in south as could be seen in Fig. 2. Spatial mapping of tea plantation areas which is a major cash crop of the district is also seen in Fig. 2.

The amount of *CRB* availability per square kilometer of geographical areas of the villages is also estimated as *CRB* intensity. It is found that about 81% of the total 1502 villages contain crop residues with varying degree of *CRB* intensity. Based on the *CRB* intensity (tonne km^{-2}), villages are classified as high (>1), medium (0.5–1) and low (<0.5) as presented in Fig. 3. The medium intensity village (453) predominates in Sonitpur district followed by low (439) and high (331) intensity. However, the scenario might get changed with change of cropping intensity. Availability of *CRB* in the remaining 19% villages (279 villages) is not certain as these are mostly affected by the river Brahmaputra and its tributaries.

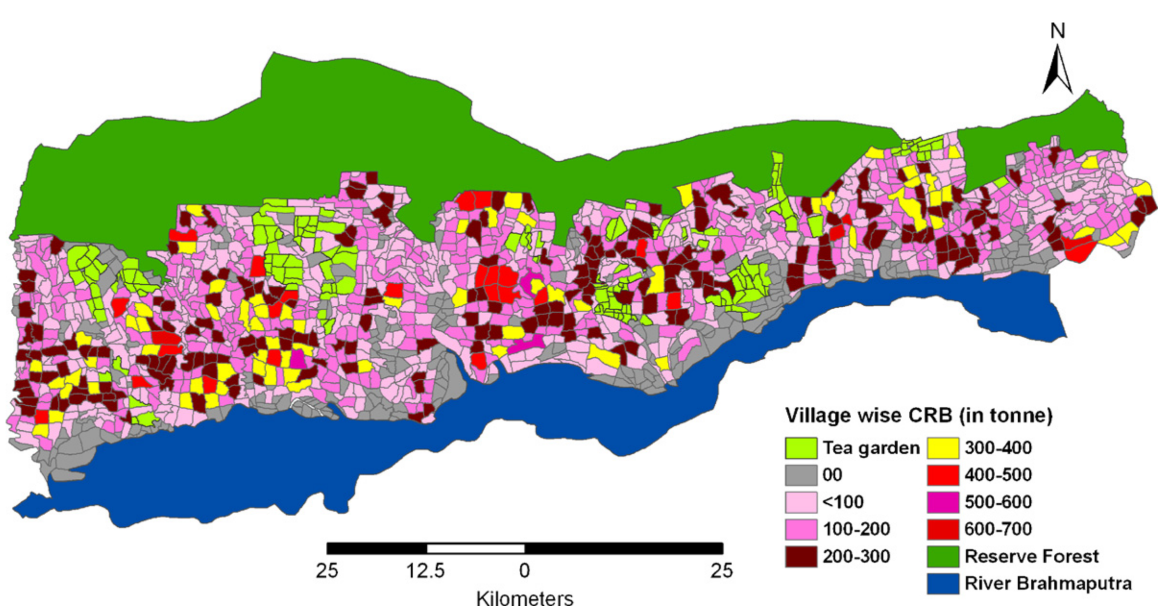


Fig. 2. Village wise crop residue biomass availability in Sonitpur district.

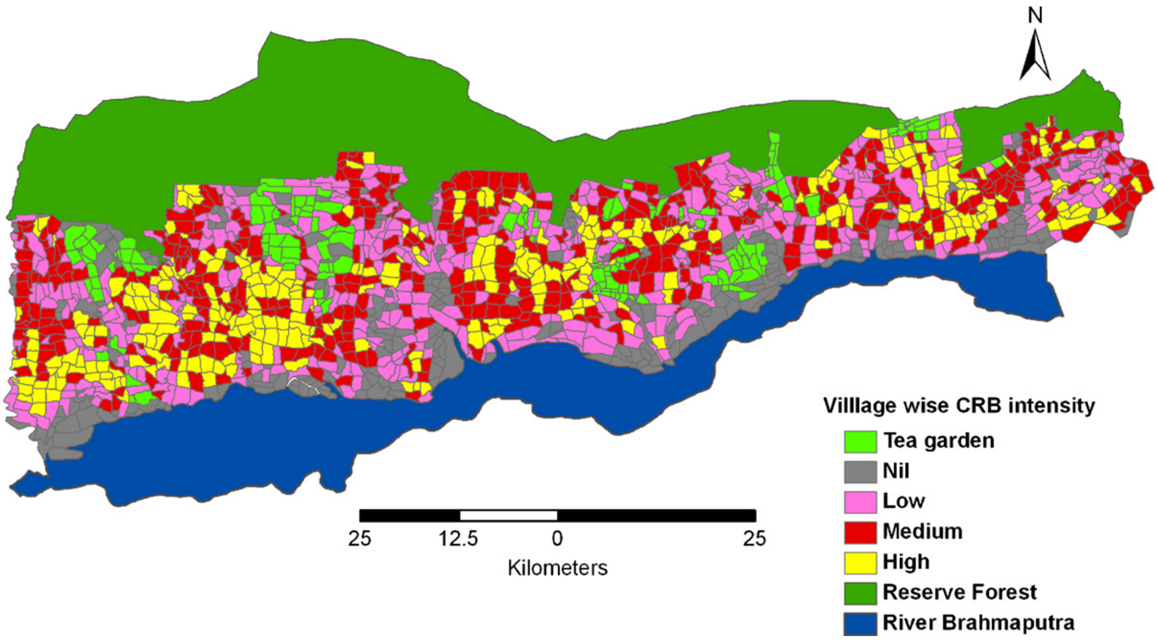


Fig. 3. Village wise crop residue biomass intensity in Sonitpur district.

3.2. Spatial availability of crop residue biomass power

Overall, accumulated *CRBP* potential in the district is estimated as 16.94 MW. However, there exist variations of the *CRBP* potential amongst the villages as presented in Fig. 4 and summarized in Table 5. Dominancy of smaller *CRBP* potential is observed amongst the villages of Sonitpur district. Majority of the villages (548 villages) have less than 10 kW potential *CRBP* in each village.

The highest individual potential of 71.86 kW power is observed in one village (No. 1 Charaibari) of Pub-Choiduar DB followed by 65.55 kW (Bengabari village) of Behali DB and 62.74 kW (Keheru Khanda) village of Dhekiajuli DB.

In the present study, the sizes of the potential power plant have been determined for continuous operation throughout the year. However, considering the existing pattern of rural electricity demand, the duration of power generation could be reduced. Presently, only domestic loads containing lighting, fan, and TV *etc.* dominate the rural electricity demand. Accordingly, the larger size power plant could be planned than the assessment made above, if operating hours are reduced. For example, sizes of the plant would be double, if generation is planned for 12 h a day, which would fulfil the critical needs of the rural people. While planning the installation of residue based power plants, due consideration must be given for the characteristics of connected loads, existing as well as future case to case basis.

3.3. Prevailing rural scenario and prospective demand for electricity

The power scenario of rural India is characterized by fluctuating voltage, unreliable supply and shortage of power [10]. As per census of India, 2001 there are 119,570 unelectrified villages in India

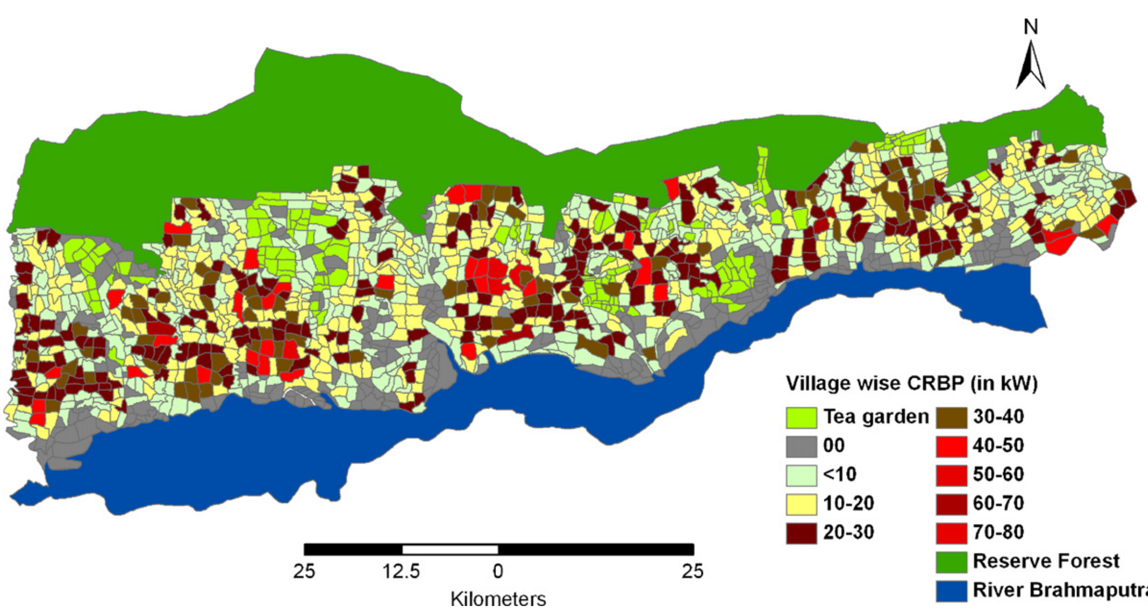


Fig. 4. Village wise crop residue biomass power potential in Sonitpur district.

Table 5
Village wise crop residue biomass power potential in villages of Sonitpur district.

CRBP potential, kW	Number of village	Group total of *CRBP* potential, kW
<10	548	2433.76
10–20	363	5358.93
20–30	202	4924.14
30–40	72	2434.20
40–50	30	1317.54
50–60	4	212.92
60–70	3	188.55
70–80	1	71.86

and more than 70 millions of household are without access to electricity. However a nationwide village electrification programme is implemented by the Govt. of India under the *Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)* for rural electrification in 2005 but more than 58,000 of villages are yet to be covered under the programme [32].

Non-access to electricity and rural poverty are closely correlated. Electricity is a pre-requisite for improving living standard, also an essential input for productive and economic activities [33]. Poor electricity supply not only hampers household activities but also badly affect health facilities, education system and agricultural activities in rural areas. The growth of rural industries including agro based industries is also badly affected due to inadequate supply of assured electricity in rural areas. This in turn has resulted in unemployment and associated socio-political problems in this region.

At present commercial activities covering the entire state of Assam (rural as well as towns and sub-urban areas) rely on diesel run generator set with unfavourable economy for electricity. Moreover, dependence of rural people on kerosene and wick lamps leads to poor quality of light, indoor air pollution [34] and associated health problems [35]. Thus, overall the paucity of electricity supply has caused multifaceted difficulties in this region. Any measures aiming to solve these issues will be a boom. Considering these issues, crop residue based decentralized power projects would be an attractive option for Sonitpur district of Assam.

4. Conclusion

The present study makes an attempt to investigate crop residue biomass availability for power generation at village level using spatial tools. Rice based mono-cropping has been the predominant practice till now in Assam. The result indicates variation in *CRB* availability and subsequently *CRBP* potential at village level in Sonitpur district. Theoretical availability of *CRB* in Sonitpur district is estimated as 0.28 million tonnes, out of which 0.17 million tonnes would be practically available for bio-energy.

It is found that about 81% of the villages contain crop residues with varying degree of *CRB* intensity (tonne km^{-2}). The medium intensity village (453) predominates in Sonitpur district followed by low (439) and high (331) intensity.

Overall, accumulated *CRBP* potential in the district is estimated as 16.94 MW. Dominancy of smaller *CRBP* potential is observed amongst the villages of Sonitpur district. The highest individual potential of 71.86 kW power is observed in one village (No. 1 Charaibari) of Pub-Choiduar DB followed by 65.55 kW (Bengabari village) of Behali DB and 62.74 kW (Keheru Khanda) village of Dhekiajuli DB.

Considering the acute shortage of grid connected power supply in the study area, the decentralized crop residue based power generation could be an attractive option.

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